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WIND-TUNNEL INVESTIGATION OF 20-PERCENT-CHORD

PLAIN AND FRISE AILERONS ON AN NACA 23012 AIRFOIL

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WASHINGTON

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SUMMARY

An investigation of several modifications of 20-percent-chord plain and Frise ailerons on an NACA 23012 airfoil was made in the NACA 7- by 10-foot wind tunnel. The static rolling, yawing, and hinge moments were determined and are herein presented for several angles of attack. The conditions under which aileron oscillation occurred were also determined.

The tests indicated that the oscillation of the Frise aileron was the result of an abrupt breakaway of the flow at the lower surface of the aileron nose when the aileron was deflected to some angle between -10° and -20°, the particular angle varying with the shape of the aileron and with the angle of attack of the airfoil. The flow breakaway was accompanied by a rapid increase in the hinge moment and, in general, by a decrease in the rolling moment. The tendency to oscillate was reduced or eliminated when a bulge or a nose slat was added to the lower surface of the aileron. The nose slat, moreover, increased the effective deflection range of the aileron.

The aileron-control characteristics were computed for a pursuit airplane with several of the aileron arrangements and with three assumed aileron linkages. The results presented illustrate the effects of variation of aileron floating tendency and of differential linkage and support the contention that proper adjustment of floating tendency by means of tabs, bulges, springs, or other devices, together with a suitable choice of differential linkage, offers a promising means of improving the control-force characteristics.

Internally balanced sealed ailerons with larger amounts of balance than the ailerons tested are considered promising.

INTRODUCTION

The NACA has undertaken an extensive investigation of lateral-control devices for the purpose of developing new devices and of supplying more design data on devices previously developed.

A large amount of data has been published by the NACA on various arrangements of plain ailerons, but comparatively little has been published on Frise ailerons (references 1, 2, and 3). The greater part of the data available on Frise ailerons can be found in the Reports and Memoranda of the British Aeronautical Research Committee (references 4 to 9).

The investigation of this report was made primarily in an attempt to determine by means of wind-tunnel tests what modifications would be necessary to prevent the violent oscillations inherent in the Frise ailerons of a recently developed fighter airplane. The Frise ailerons tested were therefore designed to simulate the ailerons of a particular airplane. They are not representative of all Frise ailerons because, as stated in reference 3 and verified in the present investigation, the shape of Frise ailerons greatly affects their characteristics. The modifications made to the aileron during the investigation were, in general, modifications that could easily be made on the existing airplane. Tests of a plain sealed aileron without balance were included for comparison.

APPARATUS AND METHODS

Tests were made in the NACA 7- by 10-foot closed-throat wind tunnel (reference 10) at an air speed of about 40 miles per hour, corresponding to a test Reynolds number of approximately 1,440,000. Some of the tests were repeated at an air speed of about 80 miles per hour, corresponding to a test Reynolds number of approximately 2,880,000. The test set-up is shown schematically in figure 1. The various 0.20c ailerons (fig. 2) were installed on the outboard 0.37 b/2 of the 4- by 8-foot NACA 23012 airfoil.

The airfoil was suspended horizontally in the wind tunnel with the inboard end attached to the tunnel wall to

simulate the semispan of a 16-foot wing. The attachment
at the wall restrained the airfoil in pitch but not in
roll or yaw. The forces necessary to restrain the out-
board end of the airfoil were measured by the regular bal-
ance system. The rolling moments were computed from the
difference in the vertical reactions at the outboard end
with the aileron neutral and in the reactions with the ai-
leron deflected; the yawing moments were similarly com-
puted from the horizontal reactions. The lift coeffi-
cients of the airfoil in the tunnel were computed from
the vertical outboard reaction with the aileron held at
neutral and under the assumption that the lateral center
of pressure of the semispan was 0.45 b/2 from the plane of
symmetry.

The aileron was manually operated by a crank outside
the tunnel near the inboard end of the wing, and the hinge
moments were computed from the twist of a calibrated torque
rod connecting the crank and the aileron. All the ailer-
ons were approximately balanced statically and a relative-
ly limber torque rod was used in order that any tendency
of the ailerons to oscillate might be easily noticed. Be-
cause the capacity of the torque rod was necessarily limit-
ed, it was impossible to obtain all of the hinge moments
in tests that were made at 80 miles per hour. When the
hinge moments became too large for the capacity of the
torque rod, the rolling and the yawing moments were deter-
mined with the aileron locked at the various deflections
by means of a small clamp at the aileron.

RESULTS AND DISCUSSION

Coefficients

The results of the tests are presented in figures 3
to 10 as curves of rolling-, yawing-, and hinge-moment co-
efficients plotted against aileron deflection at several
angles of attack for each aileron. The deflections at
which the various ailerons began to oscillate are noted by
arrows on the appropriate hinge-moment coefficient curves.

The symbols used in presenting the results are:

C_L lift coefficient (L/qS)

C_l' rolling-moment coefficient (L'/qbS)

$C_n{}'$ yawing-moment coefficient (N'/qbS)

C_h aileron hinge-moment coefficient (H_a/qS_ac_a)

c wing chord

c_a aileron chord measured along airfoil chord line from hinge axis of aileron to trailing edge of airfoil

b twice span of semispan model

S twice area of semispan model

S_a aileron area behind hinge line

L twice lift on semispan model

L' rolling moment about wind axis

N' yawing moment about wind axis

H_a aileron hinge moment about hinge axis

q dynamic pressure of air stream $(\tfrac{1}{2}\rho V^2)$

α angle of attack of airfoil in tunnel

δ_a aileron deflection, positive when trailing edge is down

δ_s nose slat deflection, positive when trailing edge is down

C_{l_p} rate of change of rolling-moment coefficient $C_l{}'$ with helix angle $pb/2V$

F_s stick force

δ_s stick angle

R differential-crank length

A positive value of L' or $C_l{}'$ corresponds to a decrease in lift on the model, and a positive value of N' or $C_n{}'$ corresponds to an increase in drag on the model. Twice the actual lift, area, and span of the model were used in the reduction of the results because the model

represented half of a complete wing, as has been previously
stated. No corrections have been made to the data for the
effect of the tunnel walls. Although such corrections may
be relatively large for this set-up, the data on the vari-
ous modifications are comparable.

Wind-Tunnel Data

Plain sealed aileron without balance.- The aerodynamic
characteristics of the plain sealed aileron without balance
are shown in figure 3. This aileron had fairly large
hinge-moment-curve slopes $(dC_h/d\delta_a)$ and an upfloating
tendency that increased with angle of attack. No oscilla-
tion of the aileron was noticed during the tests.

Plain aileron with 0.326c_a balance.- The aerodynamic
characteristics of the plain aileron with a 0.326c_a sym-
metrical nose balance, sealed, unsealed, and with two ar-
rangements of cover plates, are shown in figure 4. The
characteristics of the unsealed aileron with only the top
cover plate in place (fig. 4(a)) were very little differ-
ent from those of the plain sealed aileron without balance
except for the expected reduction in hinge-moment-curve
slope. The same aileron with a sheet-rubber seal (fig.
4(b)) was more effective but had about the same hinge-
moment characteristics as the unsealed aileron, probably
because the seal was attached slightly behind the aileron
nose.

The addition of the bottom cover plate to the airfoil
with the balanced sealed aileron (fig. 4(c)) had compara-
tively little effect on the hinge-moment coefficients but
produced an unexplained decrease in the effectiveness of
the aileron. The only oscillation noticed in the tests of
the plain balanced aileron was a slight oscillation at 8°
angle of attack at an aileron deflection of -27.5°. (See
fig. 4(a).) Ailerons of this type but with larger amounts
of balance are considered promising, and a systematic in-
vestigation of their characteristics is recommended.

Frise aileron with 0.326c_a balance.- The aerodynamic
characteristics of the Frise aileron with 0.326c_a balance
are shown in figure 5. The unsealed Frise aileron (fig.
5(a)) was less effective at a low angle of attack and
slightly more effective at a high angle of attack than the
unsealed plain aileron (fig. 4(a)). The Frise aileron had

an upfloating tendency and a very small hinge-moment-curve
slope at low deflections, but at high deflections (10° and
-20°) the differences in hinge-moment coefficients were as
large as those of the plain ailerons. The small hinge-
moment-curve slopes at low deflections may be a contribut-
ing factor to control-free lateral instability.

Comparison of the results of figures 5(a) and 5(b)
shows the scale effect on the characteristics of the Frise
aileron. The increased speed increased the effectiveness
of the aileron at all angles of attack.

The addition of a sheet-rubber seal at the nose of the
Frise aileron (fig. 5(c)) increased the rolling-moment ef-
fectiveness of the aileron. The location of the seal (at
aileron nose instead of on upper surface near slot lip)
decreased the effectiveness of the balance, probably be-
cause the seal prevented the pressures on the wing lower
surface and ahead of the aileron from acting on top of the
aileron nose. The seal also changed the upfloating tend-
ency to a downfloating tendency. It is thought that a
seal near the upper surface of the airfoil would increase
the rolling moment without reducing the effective balance.

The addition of a trailing-edge tab, deflected -15°,
to the Frise aileron with $0.326c_a$ balance (fig. 5(d)) had
somewhat the same effect on the characteristics of the ai-
leron as did the addition of the seal, partly because of
the increased size of the aileron. This increase in size
was not considered in the computation of the hinge-moment
coefficients. The aileron with the tab, however, was not
quite so effective as the aileron with the seal.

Neither the increase in speed nor the addition of the
seal or tab had much effect on the oscillatory tendencies
of the Frise aileron with $0.326c_a$ balance. This aileron
oscillated rather violently at deflections ranging from
-16° to -25°, depending on the angle of attack. It is ap-
parent from these data and from unpublished results of
flight tests of two different installations of Frise ai-
lerons that the presence of oscillation, and the aileron
deflection at which it occurs, is dependent on the partic-
ular installation (shape, surface finish, rigidity of the
system, etc.). In some installations, Frise ailerons de-
flected upward nearly 20° have shown no apparent tendency
to oscillate. It is not generally considered advisable,
however, to permit such large deflections for this type of
aileron.

A study of the data and an observation of tufts located on the lower surface of the aileron made it apparent that the oscillation of the aileron was not what is generally called aileron flutter. With the airfoil at an angle of attack of 8° the aileron was deflected to -17° before the flow began to break away from the aileron lower surface; below this angle (-17°) the hinge moments were small. At deflections of -17° to -20° the hinge moment increased rapidly and at -20° the flow had completely broken away from the lower surface of the aileron. The elasticity of the torque rod allowed the large hinge moment occurring at $\delta_a = -20^\circ$ to return the aileron to a deflection of -15° where the flow became smooth and the hinge moment became small; here the spring effect of the torque rod again deflected the aileron to -20° and once again the flow broke away and the large hinge moment decreased the aileron deflection. This process continued until the aileron was moved to a different angle by the crank. Both portions of the hinge-moment-coefficient curve had stable slopes and, since the tufts showed that the break in the curve was a stalling phenomenon, the actual variation of the hinge-moment coefficient during the oscillation is probably that indicated by the arrows in figure 6.

The Frise aileron with $0.326c_a$ balance was then equipped with a $0.01c$ lower-surface bulge (fig. 7) to prevent flow separation at the aileron nose by increasing the radius of curvature. The same purpose could probably have been accomplished by cutting away part of the original aileron nose. The bulge slightly increased the rolling-moment effectiveness of the aileron and decreased the hinge-moment-curve slope at high deflections but produced an unstable hinge-moment-curve slope in part of the negative deflection range. The bulge also caused the upfloating tendency of the aileron to change to a downfloating tendency at low angles of attack. This change in floating tendency will tend to increase the stick forces when a conventional differential system is used and could probably be counteracted by an additional bulge on the upper surface of the aileron near the trailing edge or by a forward movement of the point of maximum thickness of the lower surface bulge.

No oscillatory tendencies were noticed in the tests of the aileron with the bulge.

Frise aileron with $0.278c_a$ balance.- The aerodynamic characteristics of the Frise aileron with $0.278c_a$ balance

are shown in figure 8. This aileron (fig. 8(a)) had a greater hinge-moment-curve slope than the Frise aileron with $0.326c_a$ balance, as was expected. The change in the amount of balance had little effect on the oscillatory tendencies of the aileron.

The addition of the 0.01c lower-surface bulge (fig. 8(b)) had approximately the same effect on the Frise aileron with $0.278c_a$ balance as it had on the Frise aileron with the larger balance. The bulge gave the aileron a downfloating tendency, decreased the hinge-moment-curve slope, and apparently eliminated the oscillatory tendencies of the aileron. The addition of a sheet-rubber seal at the nose of the aileron with the bulge (fig. 8(c)) slightly increased the rolling-moment effectiveness of the aileron but altered the hinge-moment characteristics surprisingly little relative to the large effect shown in figure 5. The seal did not change the oscillatory tendencies of the aileron.

Frise aileron with $0.293c_a$ balance.- Two tests (fig. 9) were made of a Frise aileron with a $0.298c_a$ balance of a square, unconventional shape. The upper surface of the nose remained within the wing contour at deflections up to -20°. It was thought that this modification might decrease the oscillatory tendencies of the aileron. Instead, the aileron was less effective, had larger hinge-moment coefficients than the aileron with the $0.278c_a$ balance, and still oscillated at $\delta_a = -13.5°$. (See fig. 9.)

Frise aileron with $0.278c_a$ balance and a nose slat.- The aerodynamic characteristics of the Frise aileron with $0.278c_a$ balance and a nose slat (NACA 22 section) are shown in figure 10. The nose slat set at 17° (fig. 10(a)) increased the rolling-moment effectiveness and balance and reduced the oscillatory tendencies of the aileron. Increasing the slat angle to 28° (fig. 10(b)) made the aileron almost as effective as the plain sealed aileron without balance, reduced the hinge-moment coefficients at high deflections, and improved the oscillatory tendencies still more. Adding a sheet-rubber seal at the nose of the aileron with the slat at 28° (fig. 10(c)) had little effect on the characteristics of the aileron except to increase the rolling-moment effectiveness slightly at moderate deflections.

It should be noted that the slat span was only 0.31 b/2

while the aileron span was 0.37 b/2; a slat the full
length of the aileron would probably be more effective.
Also, since only two slat arrangements were tested, it is
probable that neither the deflection nor the position of
the slat was the optimum. These tests indicated, however,
that slats may be very useful on control surfaces.

Application of Data

The aileron-control characteristics of a pursuit air-
plane (fig. 11) equipped with several aileron arrangements
with an equal up-and-down linkage (+15°) and a differential
linkage of the same total deflection (fig. 12) have been
computed and are presented in figures 13 and 14. For sim-
plicity, these lateral-control characteristics were com-
puted from the data in figures 3., 4(b), 5(a), 5(c), 8(a),
8(b), 10(b), and 10(c) (the uncorrected aerodynamic char-
acteristics of the ailerons) without taking account of the
difference in wing plan form. The effects of rolling,
moreover, have not been considered; these effects will be
discussed later. Because the assumptions and the methods
of computation followed herein are the same as those in
references 11, 12, and 13, the computed characteristics of
the several reports are thought to be comparable. The
lift coefficient of the airplane at any particular angle
of attack was assumed to be that of the airfoil in the
wind tunnel, this coefficient being computed as previously
described under Apparatus and Methods.

As was expected, the data in figures 13 and 14 show
that the Frise ailerons, in general, had smaller stick
forces than plain ailerons of the same size for a given
value of rolling-moment coefficient. The plain ailerons,
however, were more effective than the Frise ailerons at
the same deflections. The adverse (negative) yawing-
moment coefficients of the two types of aileron were about
the same except near full aileron deflection, where the
Frise ailerons had better yawing-moment characteristics
but also had high stick forces.

With an equal up-and-down deflection the 0.15c plain
sealed aileron with $0.35c_a$ balance of reference 11 had ap-
proximately the same effectiveness and yawing-moment char-
acteristics as the 0.20c Frise unsealed aileron with
$0.326c_a$ balance and had only slightly larger stick forces.
The plain aileron also has in its favor the fact that the
amount of aerodynamic balance could probably be increased

enough to give it lower stick forces than those of the
Frise aileron at full deflection without overbalancing in
the low-deflection range. The fact that the aileron would
not be overbalanced in the low-deflection range would re-
duce the possibility of the occurrence of control-free
lateral instability. The 0.15c plain aileron, moreover,
should not tend to oscillate.

At low speeds the conventional differential system
gave lower stick forces than the equal-deflection system.
At high speeds, however, except at small deflections, the
two systems gave about equal stick forces. (See figs. 13
and 14.)

During the analysis of the data it became apparent
that the use of a reversed differential (down aileron de-
flected more than up aileron) might be advantageous when
the aileron had a downfloating tendency. This possibility
may be inferred from the analysis of aileron-linkage sys-
tems presented in reference 14. The differential shown in
figure 12 was reversed and applied to a Frise aileron with
and without a seal (fig. 15). The use of the reversed
differential slightly increased the adverse (negative)
yawing-moment coefficients. (See figs. 13(b), 14(b), and
15.)

Figure 16 is a comparison of the stick forces of an
airplane equipped with the sealed Frise aileron with three
linkages: conventional differential, equal up-and-down,
and reversed differential. The combination of downfloat-
ing tendency and reversed differential gave a considerable
reduction in the high-speed stick forces. An increase
in angle of attack decreased the downfloating tendency of
the aileron and it was estimated from other data that the
sealed aileron would float up slightly at $\alpha = 15^{\circ}$. On
the basis of this estimation an approximate curve was drawn
in figure 5(c) and from this curve the low-speed stick
forces (fig. 16) were computed. At low speed the reversed
differential and the upfloating tendency increased the
stick forces. This increase in stick force would give more
feel to the stick at low speed and less variation of stick
force with speed.

Because the floating tendency of ailerons may be con-
trolled by the use of springs, tabs, or bulges and by nose
treatment, adjustment of floating tendency and of differen-
tial offers a promising means of controlling stick forces
and stick-force variation with speed.

The effects of rolling have not been considered in the computed characteristics of figures 13 to 16. The characteristics presented are those that would exist if the airplane were restrained in roll and yaw, as is generally true of a wind-tunnel model. An airplane actually begins to roll almost immediately after the ailerons are deflected. In order to illustrate the effect of rolling upon the stick force required to produce a given rolling-moment coefficient, comparative curves are given in figure 17. The solid lines represent the static condition, in which the airplane is not permitted to roll. The broken curves represent the condition in which the airplane is rolling with a velocity such that the rolling moment due to roll is numerically equal to the rolling moment due to aileron deflection. (See reference 15 or 16.) The value of C_{l_p} for the illustrative airplane was estimated as 0.45 from the curves of reference 15 or 16.

The differences between the curves shown by the solid and the broken lines of figure 17 are almost entirely the result of the variation of aileron hinge moment with angle of attack. If comparative curves similar to those of figure 17 were drawn for plug-type ailerons (see reference 13), a reduction of stick force at a given rolling-moment coefficient would also be shown, but for those ailerons the reduction would be primarily the result of the increase of rolling-moment coefficient with angle of attack.

CONCLUSIONS

The oscillatory tendency found in some flight installations of Frise ailerons was shown by the wind-tunnel tests to be the result of an abrupt breakaway of the flow at the lower surface of the aileron nose when the aileron was deflected. This breakaway occurred at an aileron deflection between -10° and -20°, the aileron deflection varying with the angle of attack of the airfoil and with the shape of the aileron.

When the flow breakaway occurred, the hinge moment increased rapidly and the rolling moment usually decreased. It appears that Frise ailerons should be so designed that they will not be deflected to the angle at which breakaway occurs. The useful range of Frise ailerons may sometimes be increased by the addition of a nose slat or a bulge on the aileron lower surface.

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Internally balanced sealed ailerons with larger amounts
of balance than those tested are considered promising, and
a systematic investigation of their characteristics is rec-
ommended.

Because the floating tendency of ailerons may be con-
trolled by the use of springs, tabs, or bulges and by
nose treatment, adjustment of floating tendency and of
differential offers a promising means of controlling stick
forces as well as the variation of stick force with speed.

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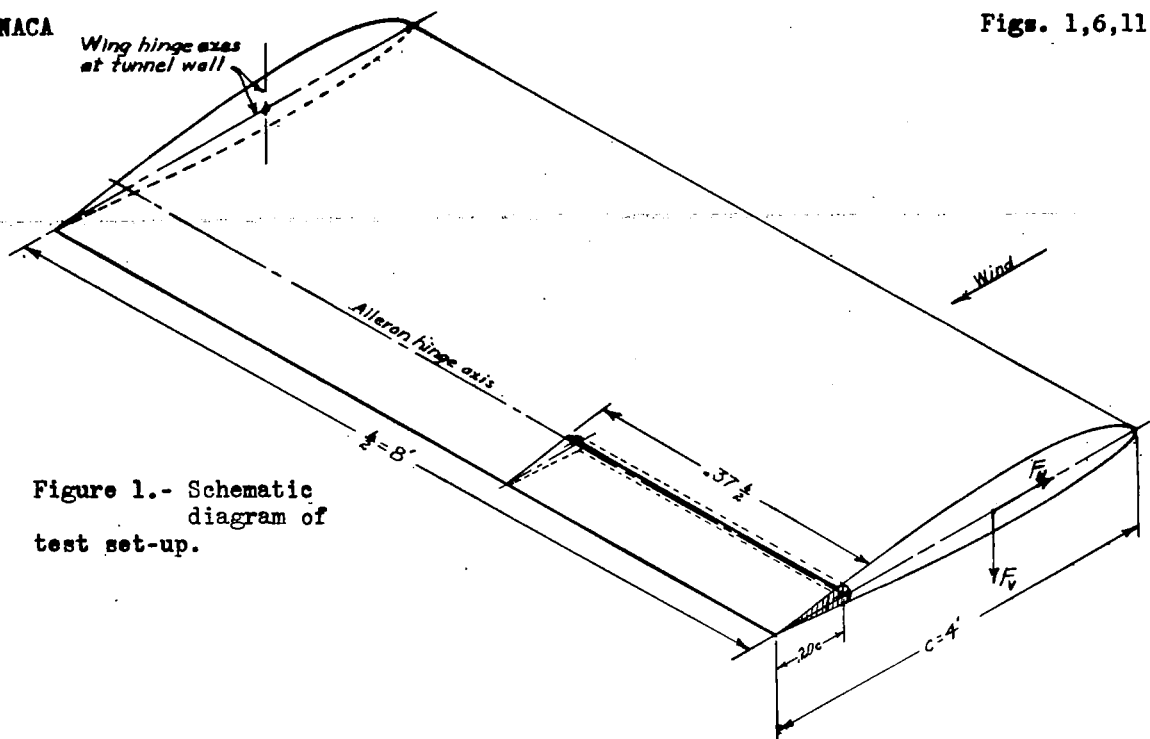   Various Amounts of Taper and Twist. Rep. No. 635,
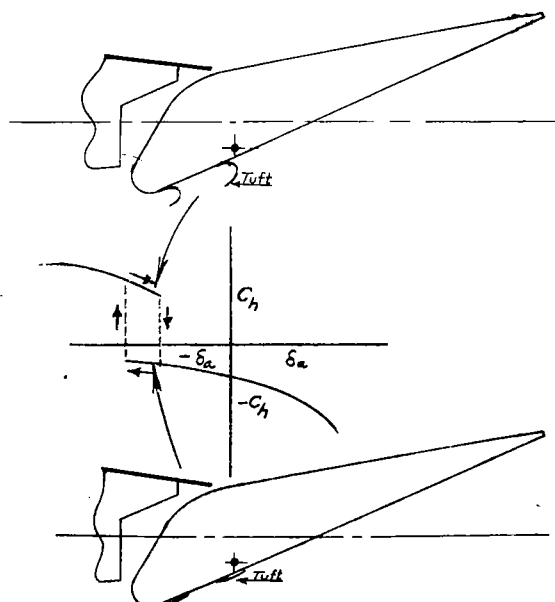   NACA, 1938.

Figure 1.- Schematic diagram of test set-up.

Figure 6.- Tuft action on the lower surface of an up-deflected Frise aileron, showing cause of oscillation.
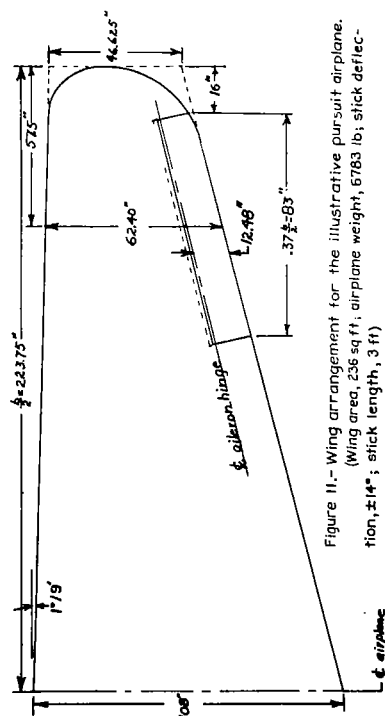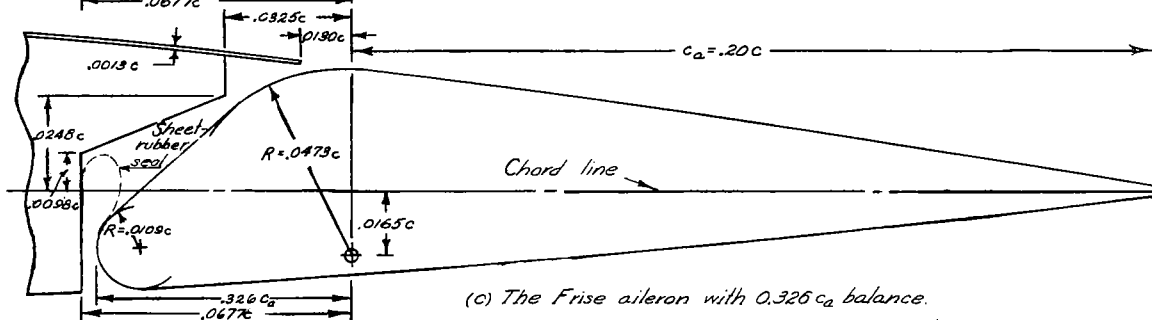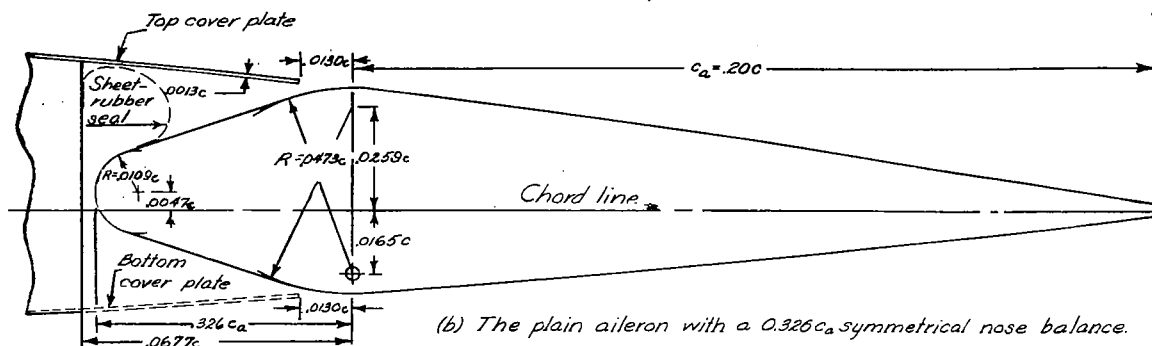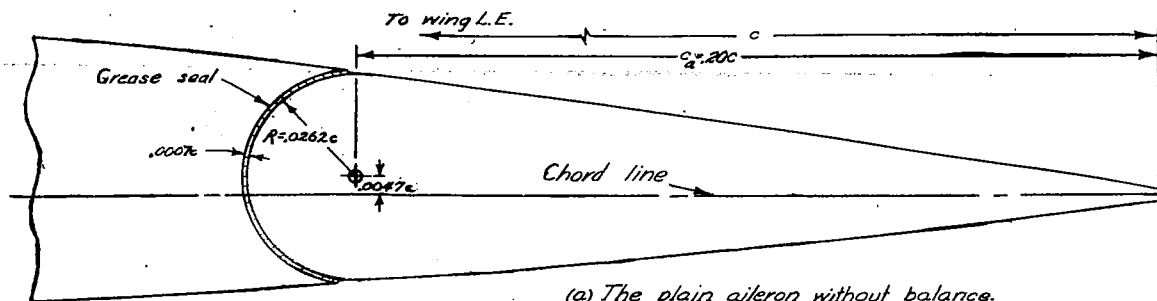

Figure 11.- Wing arrangement for the illustrative pursuit airplane. (Wing area, 236 sq ft; airplane weight, 6783 lb; stick deflection, ±14°; stick length, 3 ft)

(a) The plain aileron without balance.

(b) The plain aileron with a 0.326 c_a symmetrical nose balance.

(c) The Frise aileron with 0.326 c_a balance.

(d) The Frise aileron with 0.326 c_a balance
and a 0.01c lower-surface bulge.

(e) The 0.10 c_a by 0.37½ trailing edge
tab used on the Frise aileron.
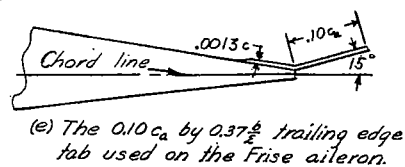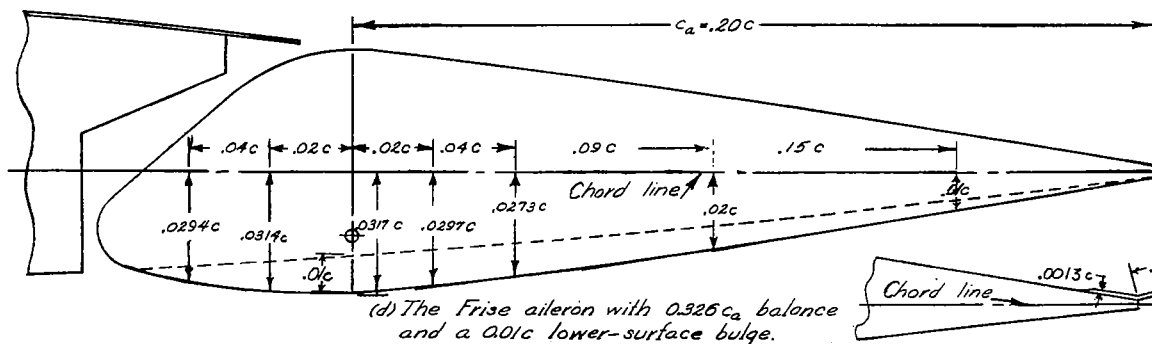
⊕ Hinge location

FIGURE 2.— The 0.20c by 0.37½ ailerons tested on the 8-foot semispan
NACA 23012 airfoil.

(f) The Frise aileron with 0.278 c_a balance.

(g) The Frise aileron with 0.298 c_a balance.

(h) The Frise aileron with 0.278 c_a balance and a 0.01 c lower surface bulge.

For $\delta_a = 17°$, $x = 0.0529c$, gap = 0.0034c

For $\delta_a = 28°$, $x = 0.0545c$, gap = 0.0033c

(i) The Frise aileron with 0.278 c_a balance and a 0.078c_a by 0.31 $\frac{c}{2}$ nose slot. (NACA 22 airfoil).

Figure 2.- Concluded.

Grease seal

Chord line

$c_a = .20c$

Chord line

$.326c_a$

$c_a = .20c$

α,deg	C_L
△ -6	-.34
○ 1	.18
□ 8	.80
◇ 15	1.43

α,deg	C_L
△ -6	-.34
○ 1	.18
□ 8	.80
◇ 15	1.43

Rolling-moment coefficient, C_l'

Yawing-moment coefficient, C_n'

Hinge-moment coefficient, C_h

None

Slight

None

No oscillation

↓ Points of oscillation

(a)

Aileron deflection, δ_a, deg

(a) No seal, top cover plate only.
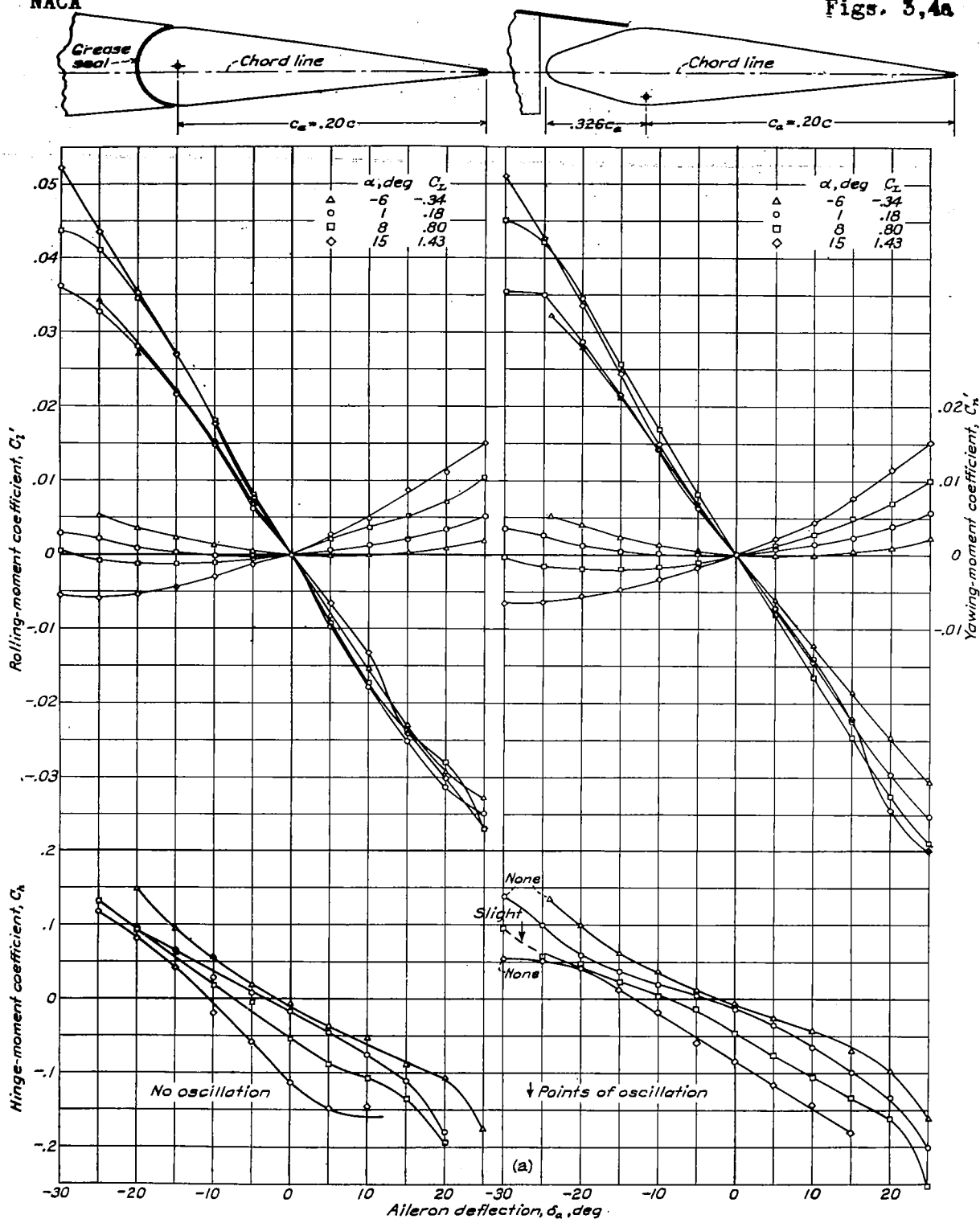
Figure 3.- Aerodynamic characteristics
of a 0.20c by 0.37 b/2
plain grease-sealed aileron without
balance on an NACA 23012 airfoil.
V, 40 mph.

Figure 4a to c.- Aerodynamic charac-
teristics of a 0.20c by
0.37 b/2 plain aileron with a $0.326c_a$
symmetrical nose balance on an NACA
23012 airfoil. V, 40 mph.
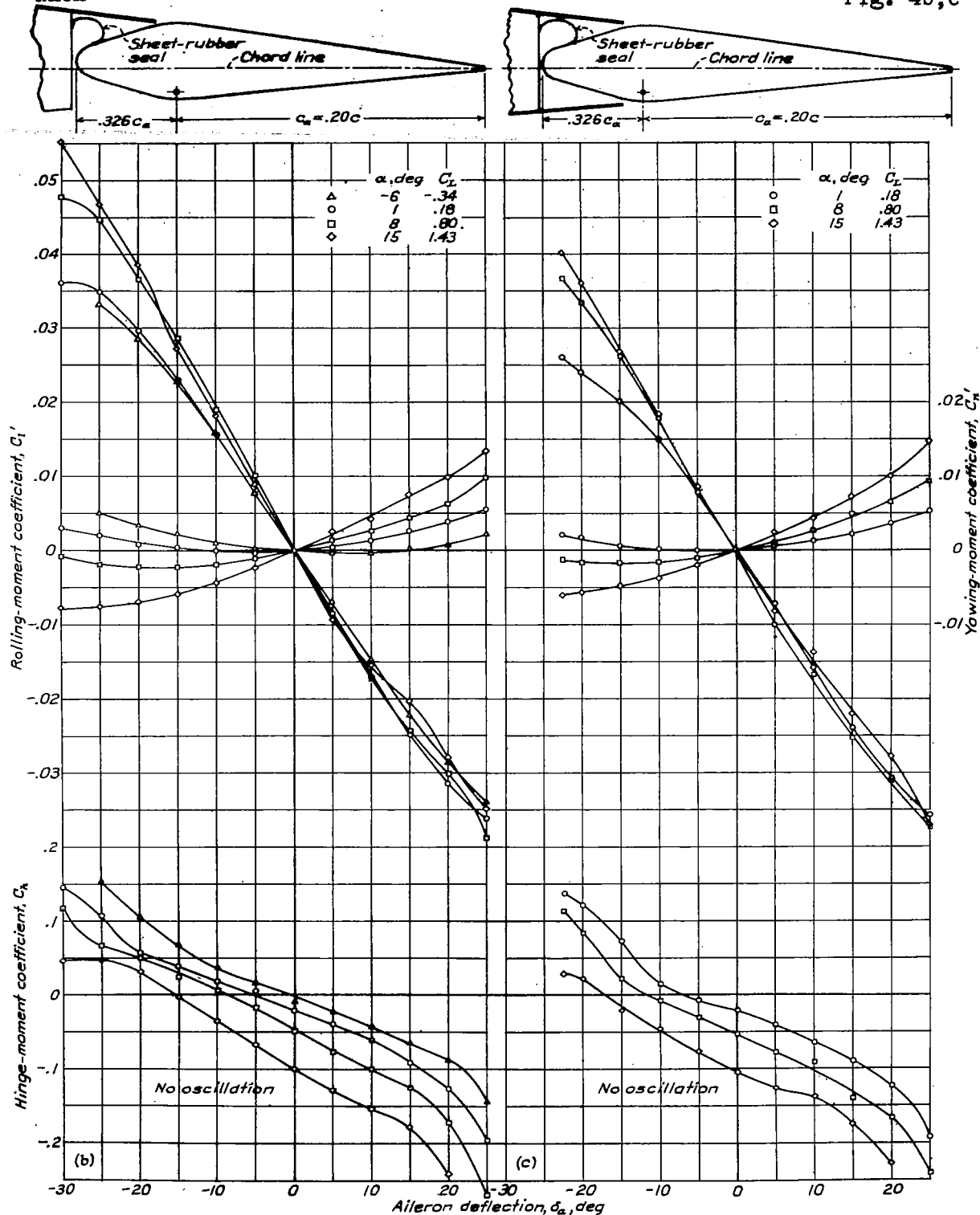
(b) Sheet-rubber seal; top cover plate only.

(c) Sheet-rubber seal; both cover plates.

Figure 4b,c.

(a) No seal; V, 40 mph.   (b) No seal; V, 80 mph.

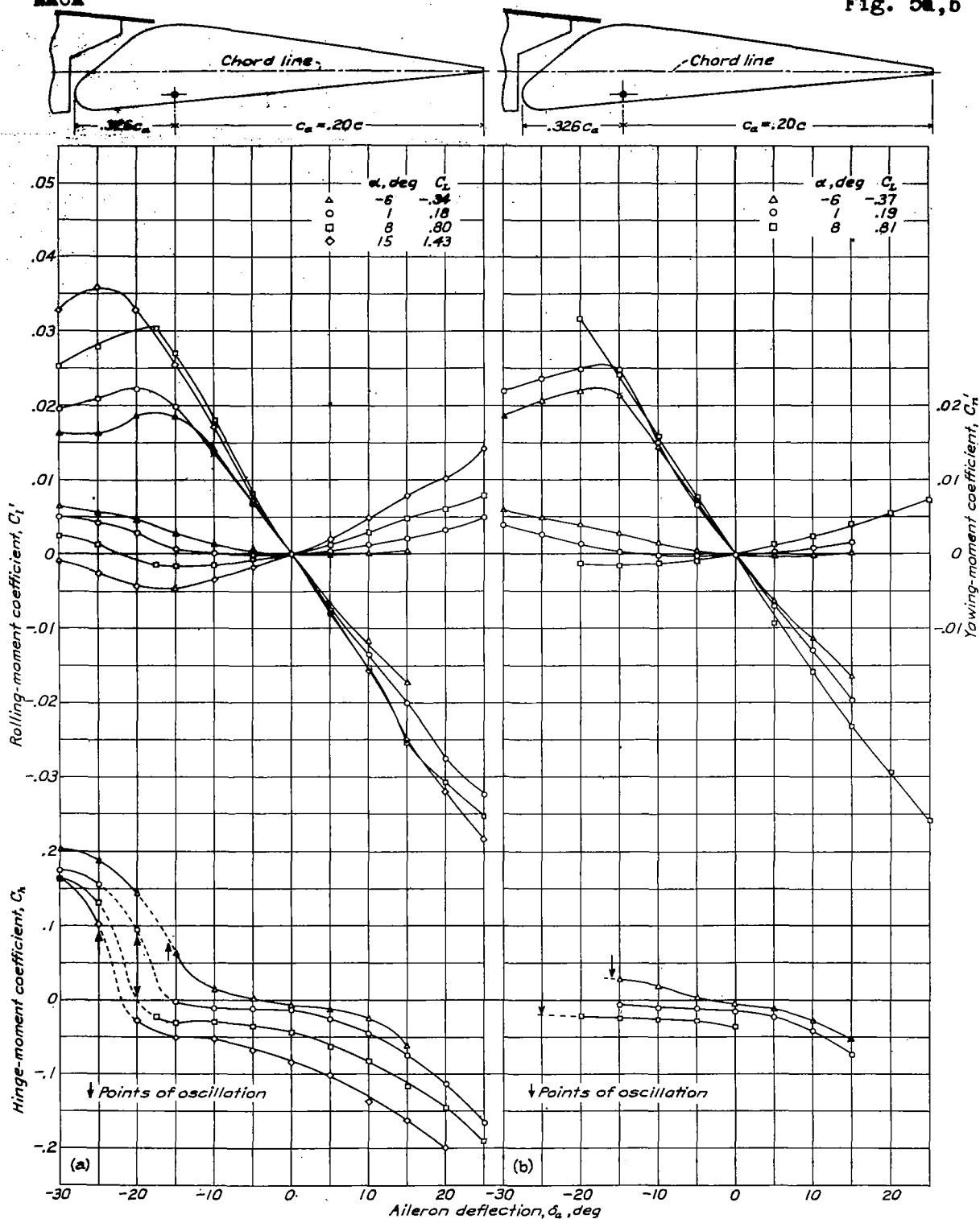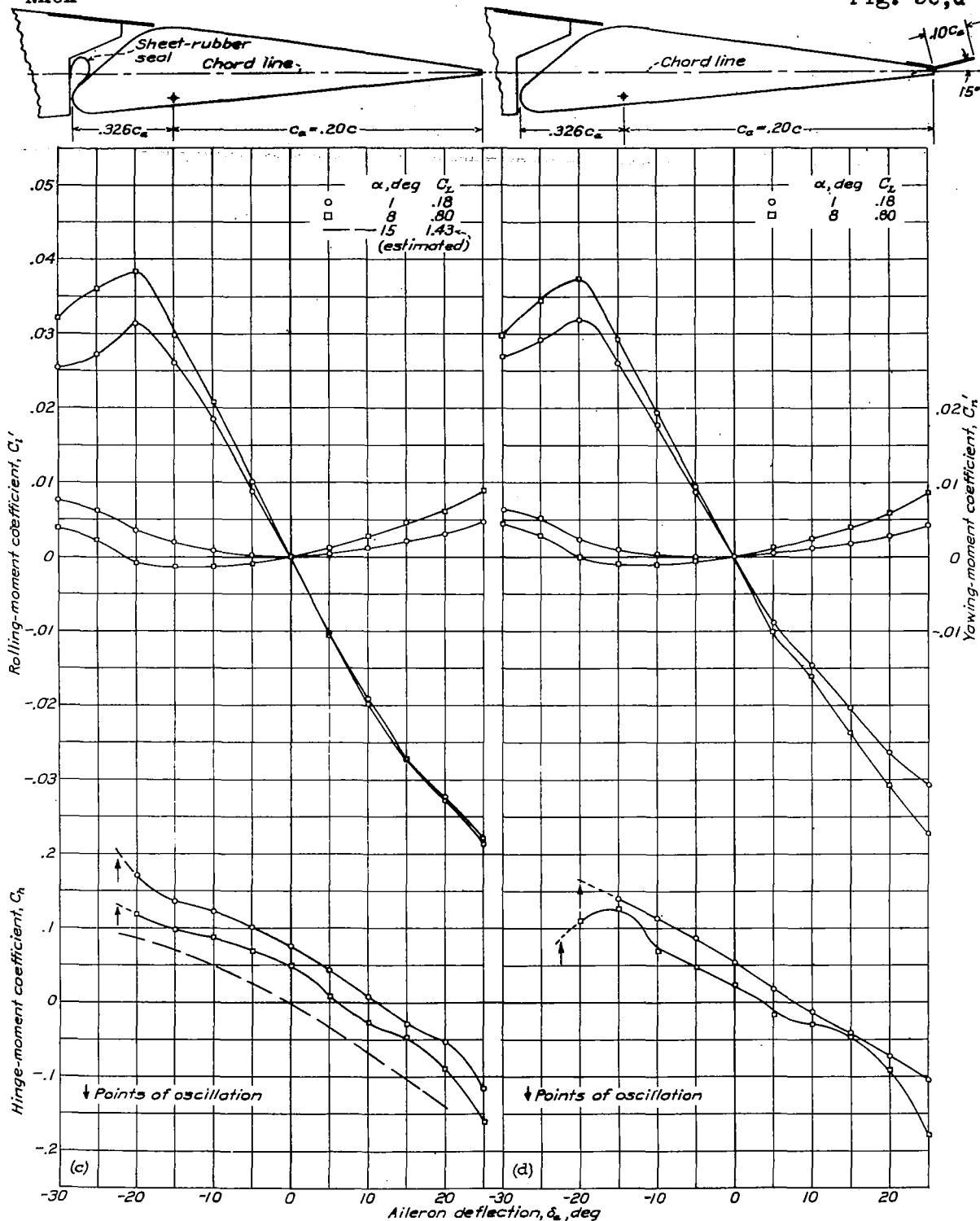Figure 5a to d.- Aerodynamic characteristics of a 0.20c by 0.37 b/2
Frise aileron with 0.326c$_a$ balance on an NACA 23012
airfoil.

(c) Sheet-rubber seal; V, 40 mph.   (d) No seal; V, 40 mph; 0.10c_a by 0.37 b/2 tab; δ_t, -15°.
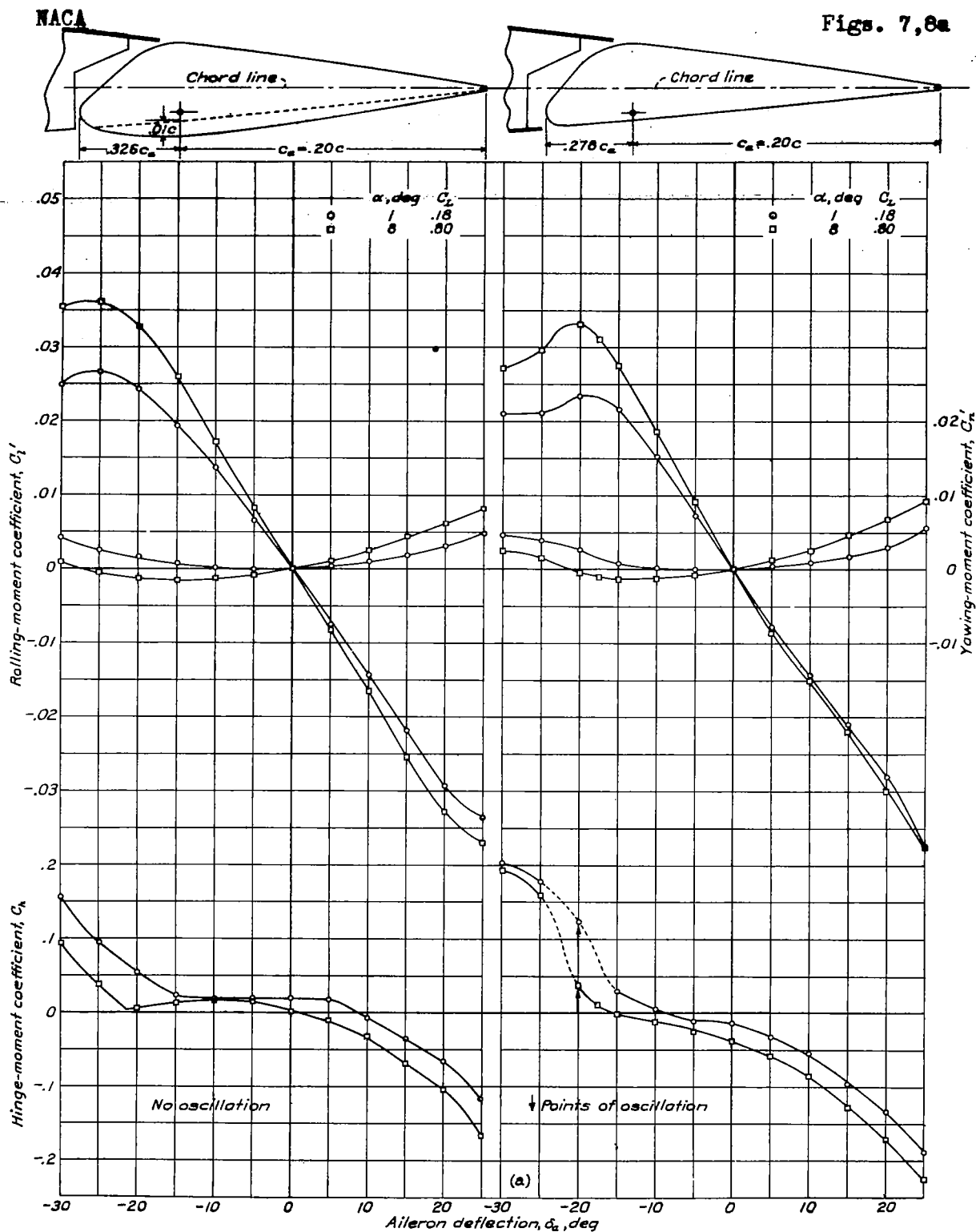
Figure 5c,d.

(a) No seal; V, 40 mph.

Figure 7.- Aerodynamic characteristics
        of a 0.20c by 0.37 b/2
Frise aileron with 0.326c_a balance and
a 0.01c lower-surface bulge on an NACA
23012 airfoil. No seal; V, 40 mph.

Figure 8a to c.- Aerodynamic
        characteristics of a 0.20c
by 0.37 b/2 Frise aileron with
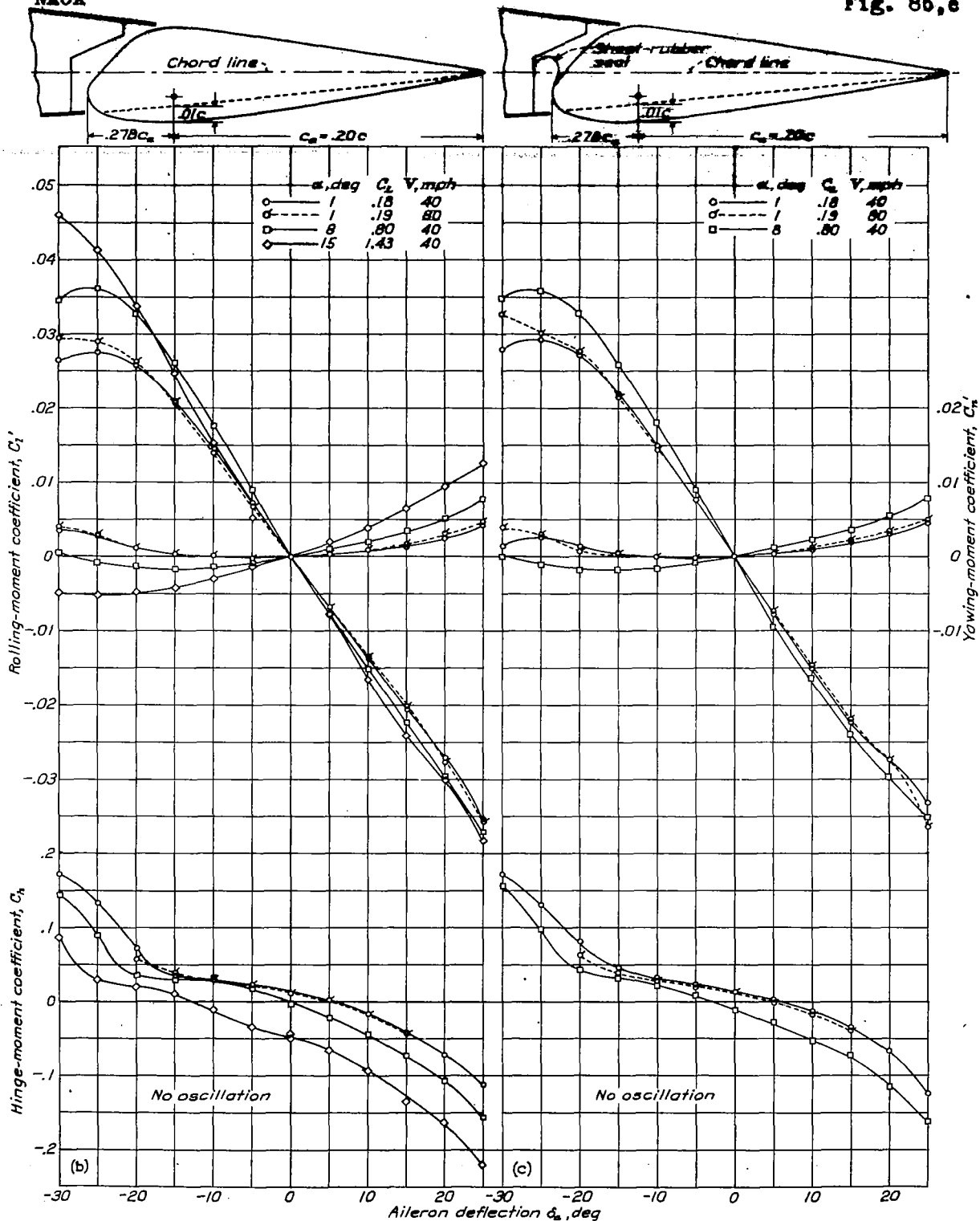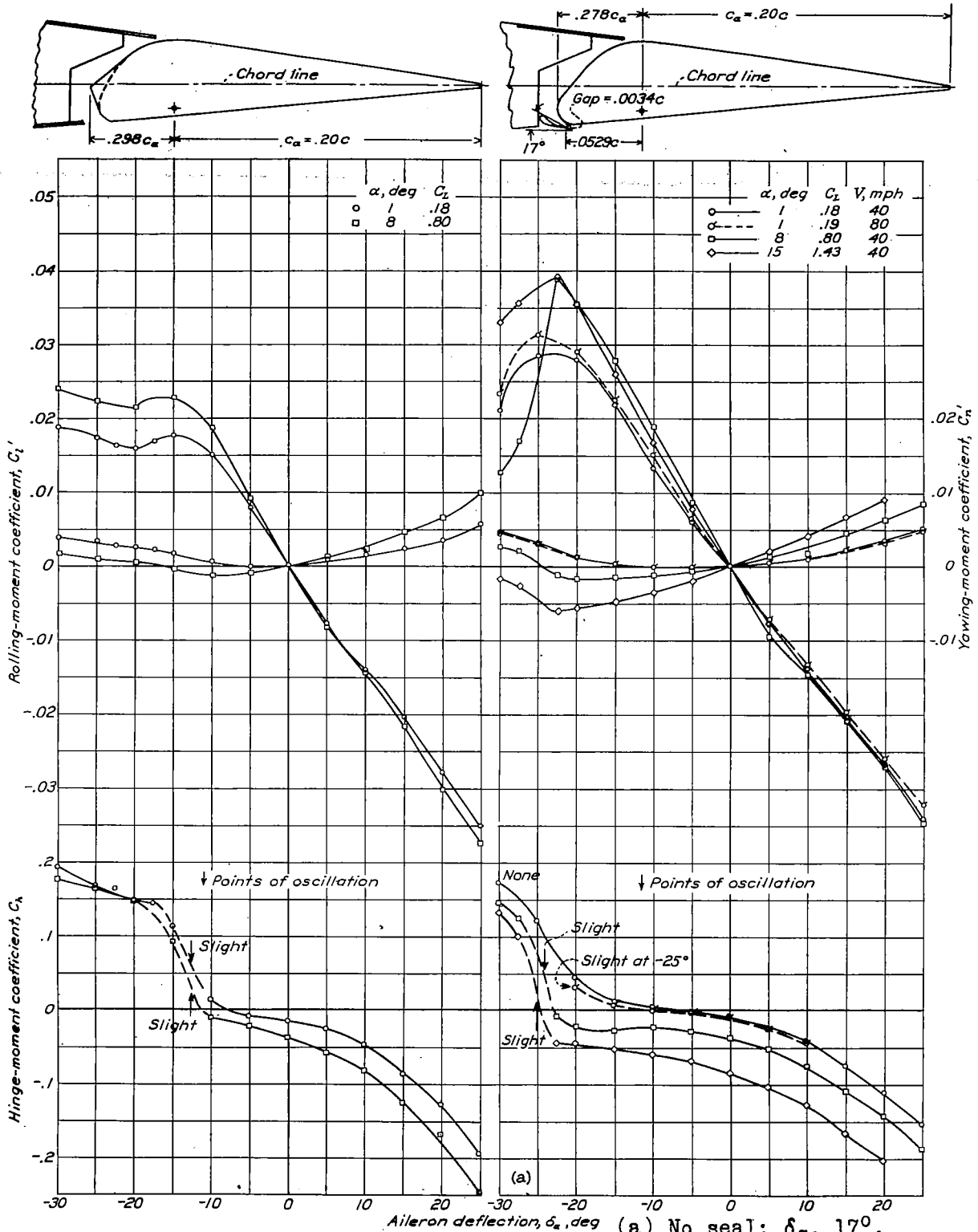0.278c_a balance on an NACA 23012
airfoil.

(b) No seal; 0.01c lower-surface   (c) Sheet-rubber seal; 0.01c lower-
    bulge.   surface bulge.

Figure 8b,c.

.278c_a c_a=.20c

.Chord line

Gap =.0034c

.298c_a c_a =.20c

17° .0529c

.Chord line

α, deg	C_L
o 1	.18
□ 8	.80

α, deg	C_L	V, mph
o 1	.18	40
o 1	.19	80
□ 8	.80	40
◇ 15	1.43	40

Rolling-moment coefficient, C_l'

Yawing-moment coefficient, C_n'

Hinge-moment coefficient, C_h

↓ Points of oscillation

Slight

Slight

None

↓ Points of oscillation

Slight

Slight at -25°

Slight

(a)

-30 -20 -10 0 10 20 -30 -20 -10 0 10 20

Aileron deflection, δ_a, deg (a) No seal; δ_s, 17°.

Figure 9.- Aerodynamic characteristics of a 0.20c by 0.37 b/2 Frise aileron with 0.298c_a balance on an NACA 23012 airfoil. No seal; V, 40 mph.

Figure 10a to c.- Aerodynamic characteristics of a 0.20c by 0.37 b/2 Frise aileron with 0.278c_a balance and a centrally located 0.078c_a by 0.31 b/2 nose slat on an NACA 23012 airfoil.

(b) No seal; δ_s, 28°.

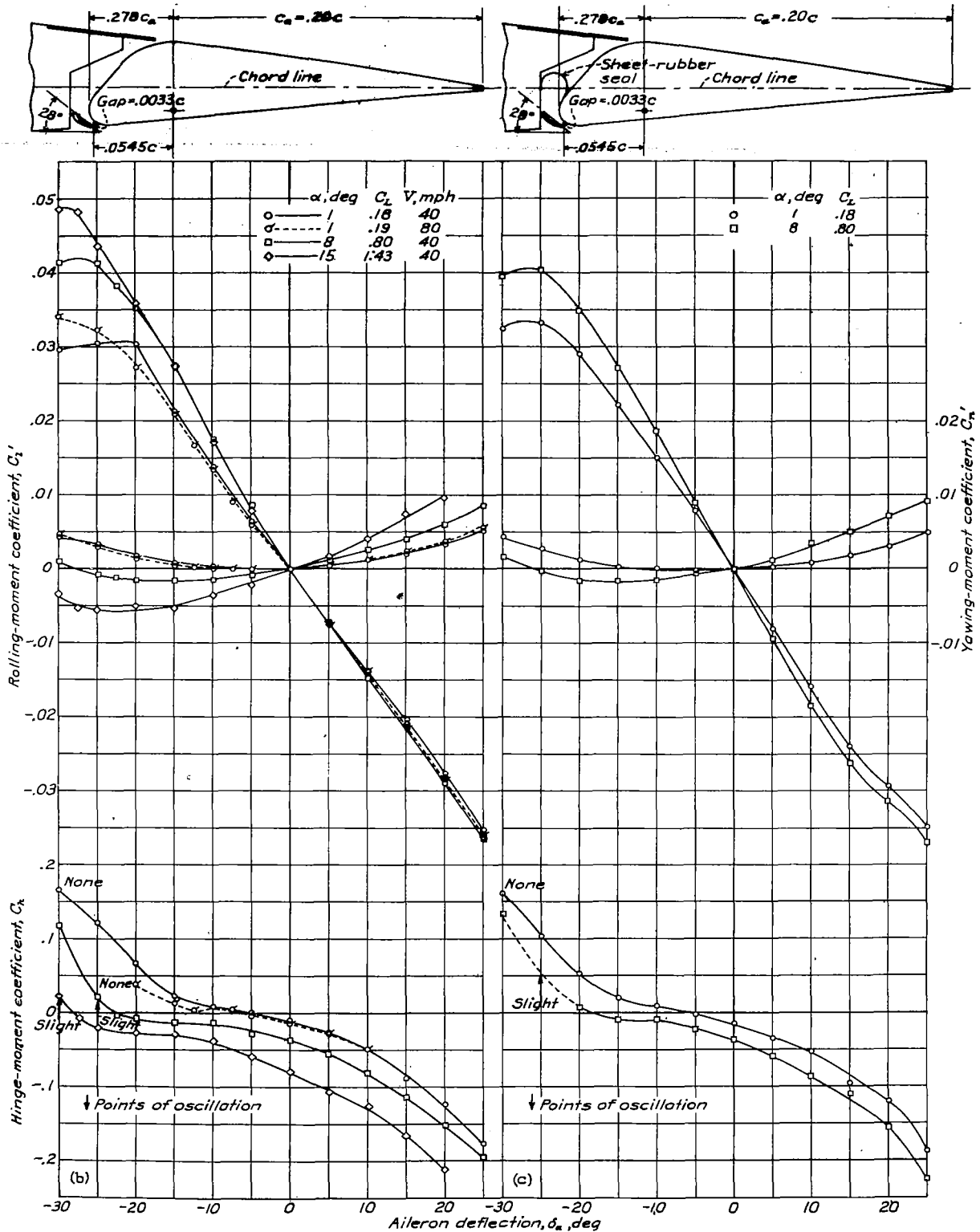(c) Sheet-rubber seal; δ_a, 28°; V, 40 mph.
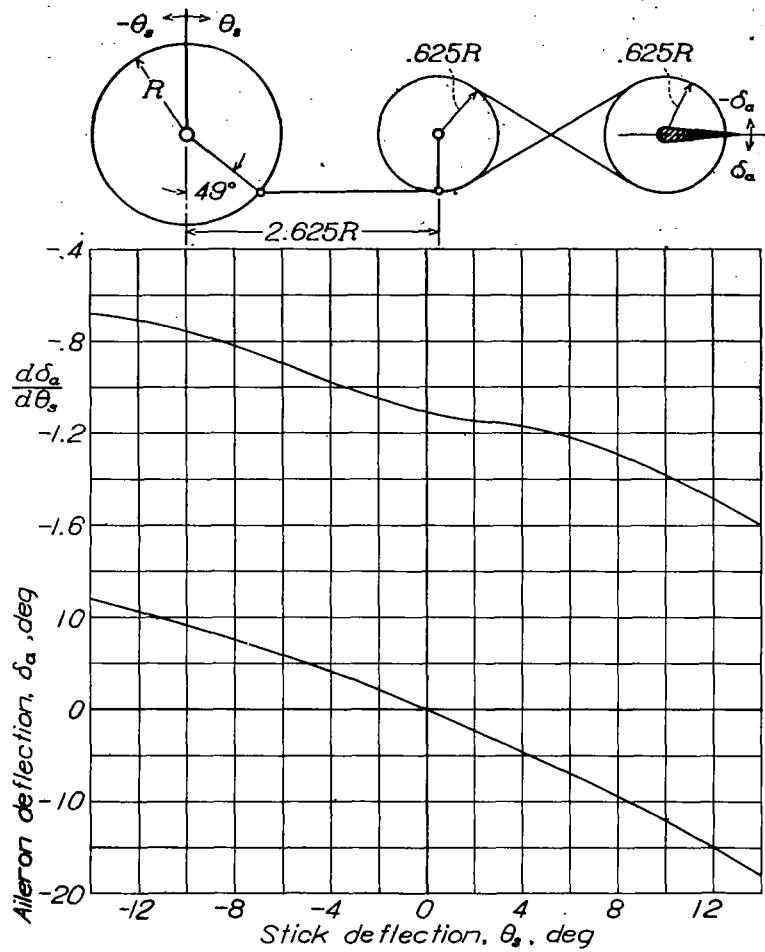
Figure 10b,c.

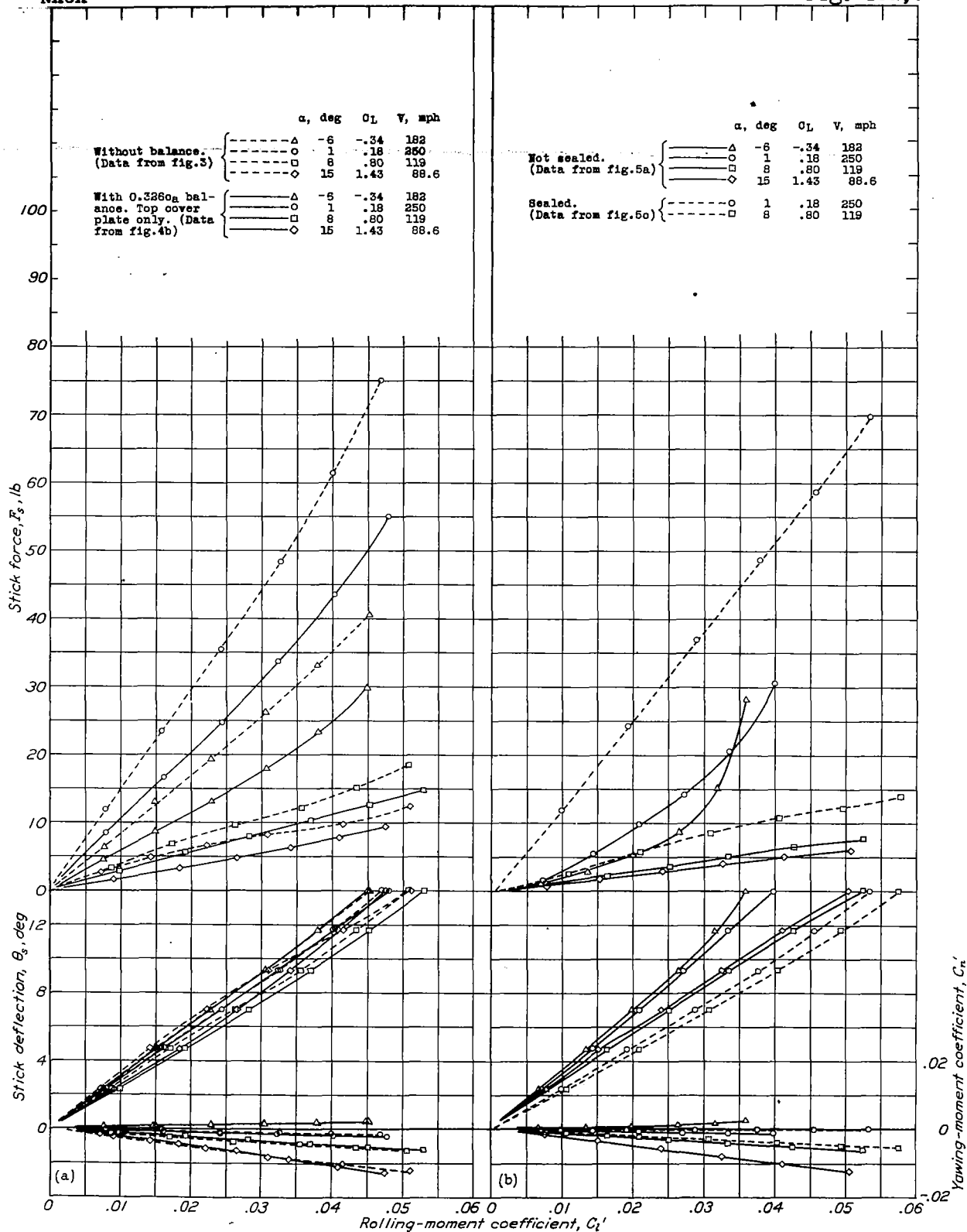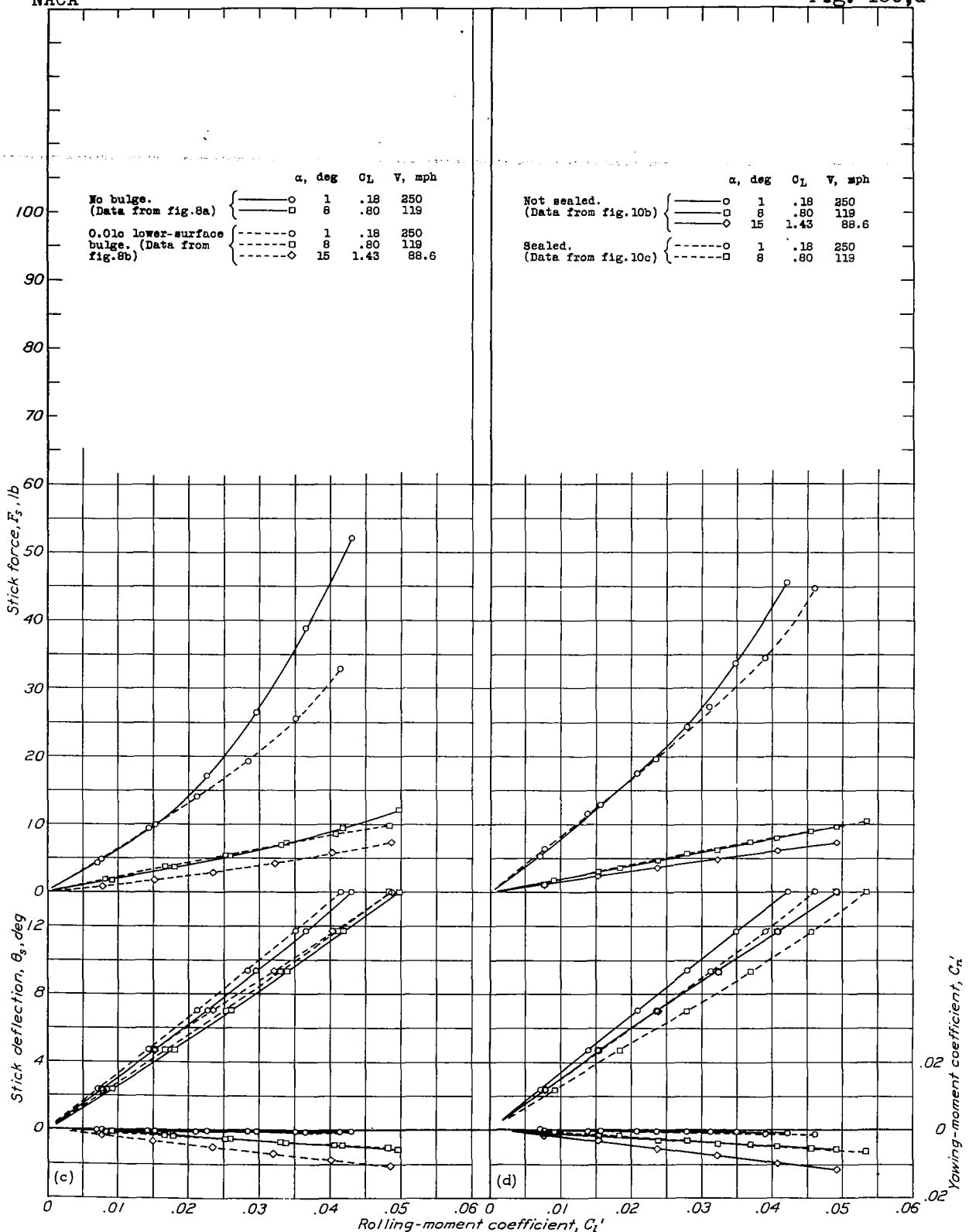Figure 12.- Conventional differential aileron linkage assumed in the computations.
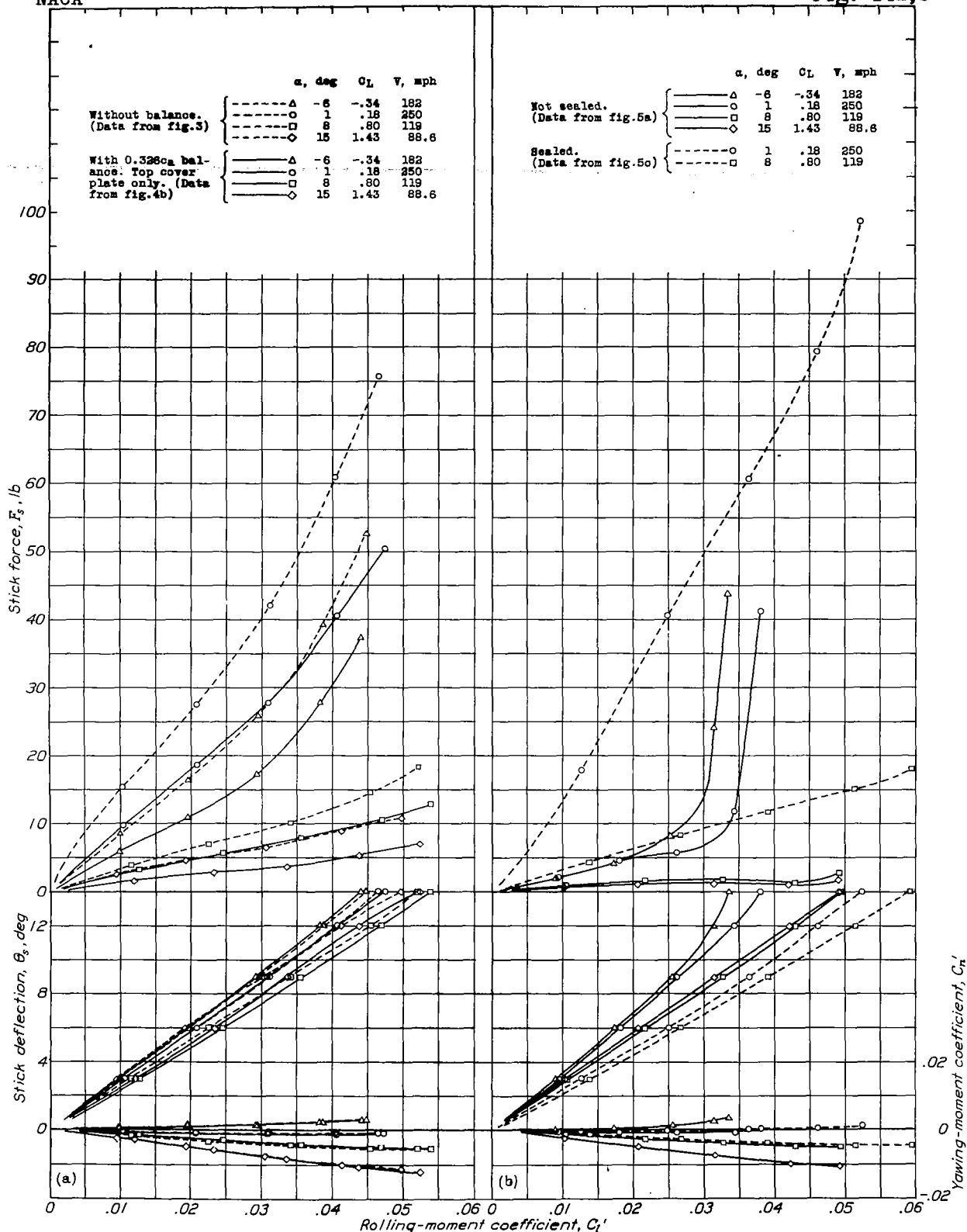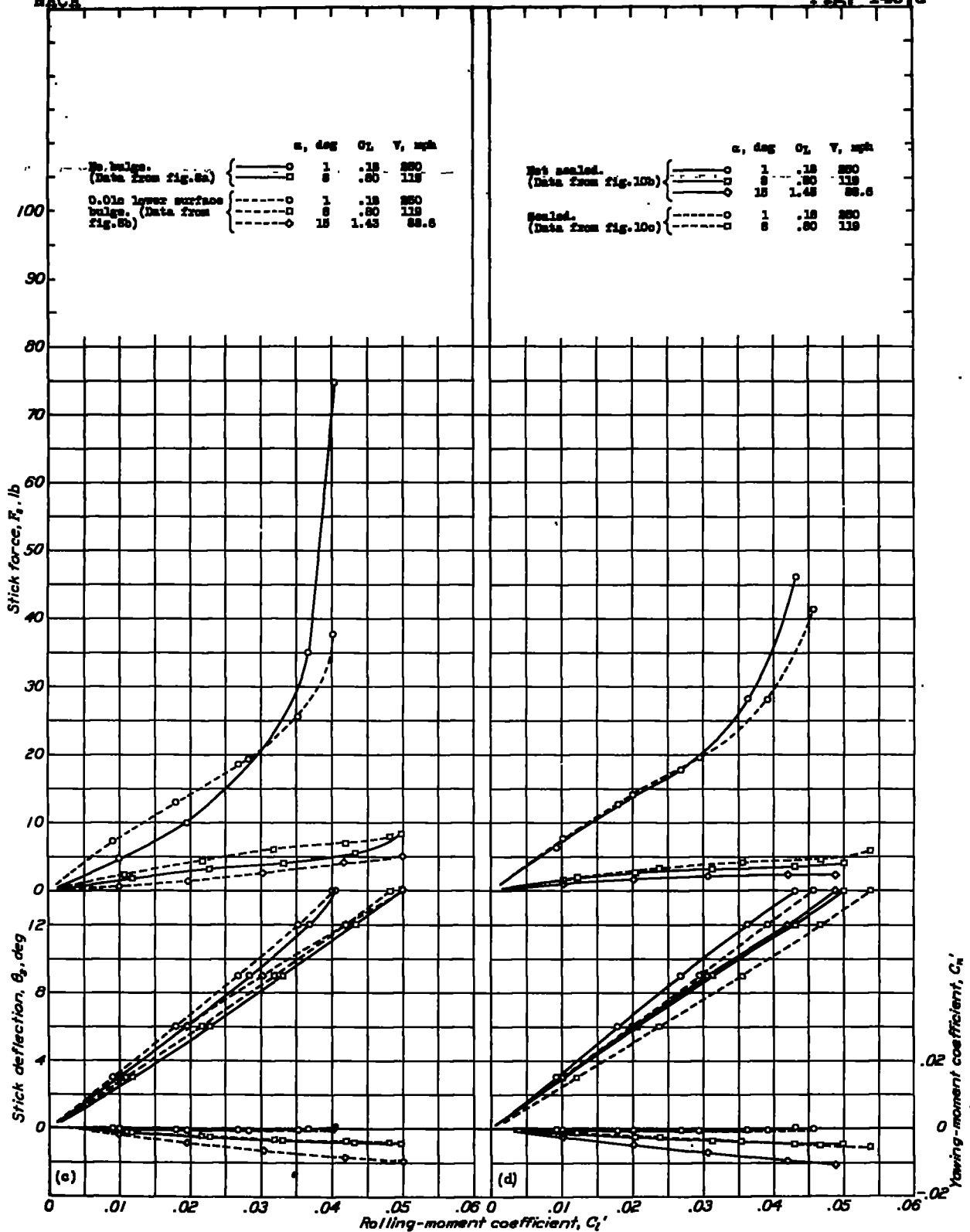
(a) Plain sealed ailerons. (b) Frise aileron with 0.326c_a balance, no bulge.
Figure 13a to d.- Aileron-control characteristics of a pursuit airplane equipped
with several arrangements of 0.20c by 0.37 b/2 ailerons.
Equal up and down linkage. δ_a, ±15°.

(c) Frise ailerons with $0.278c_a$ balance; not sealed.

(d) Frise aileron with $0.278c_a$ balance and a nose slat; δ_s, 28°.

Figure 13c,d.

(a) Plain sealed aileron.   (b) Frise aileron with 0.326c_a balance; no bulge.
Figure 14a to d.- Aileron-control characteristics of a pursuit airplane equipped
with several arrangements of 0.20c by 0.37 b/2 ailerons.
Conventional differential linkage. δ_a,+12°, -18°.

(c) Frise ailerons with 0.278c_a balance; not sealed.

(d) Frise aileron with 0.278c_a balance and a nose slat; δ_s, 28°

Figure 14c,d.

Figure 16.- Effect of aileron linkage on the stick-force characteristics of a pursuit airplane equipped with 0.20c by 0.37 b/2 sealed Frise ailerons with 0.326c$_a$ balance; no bulge.
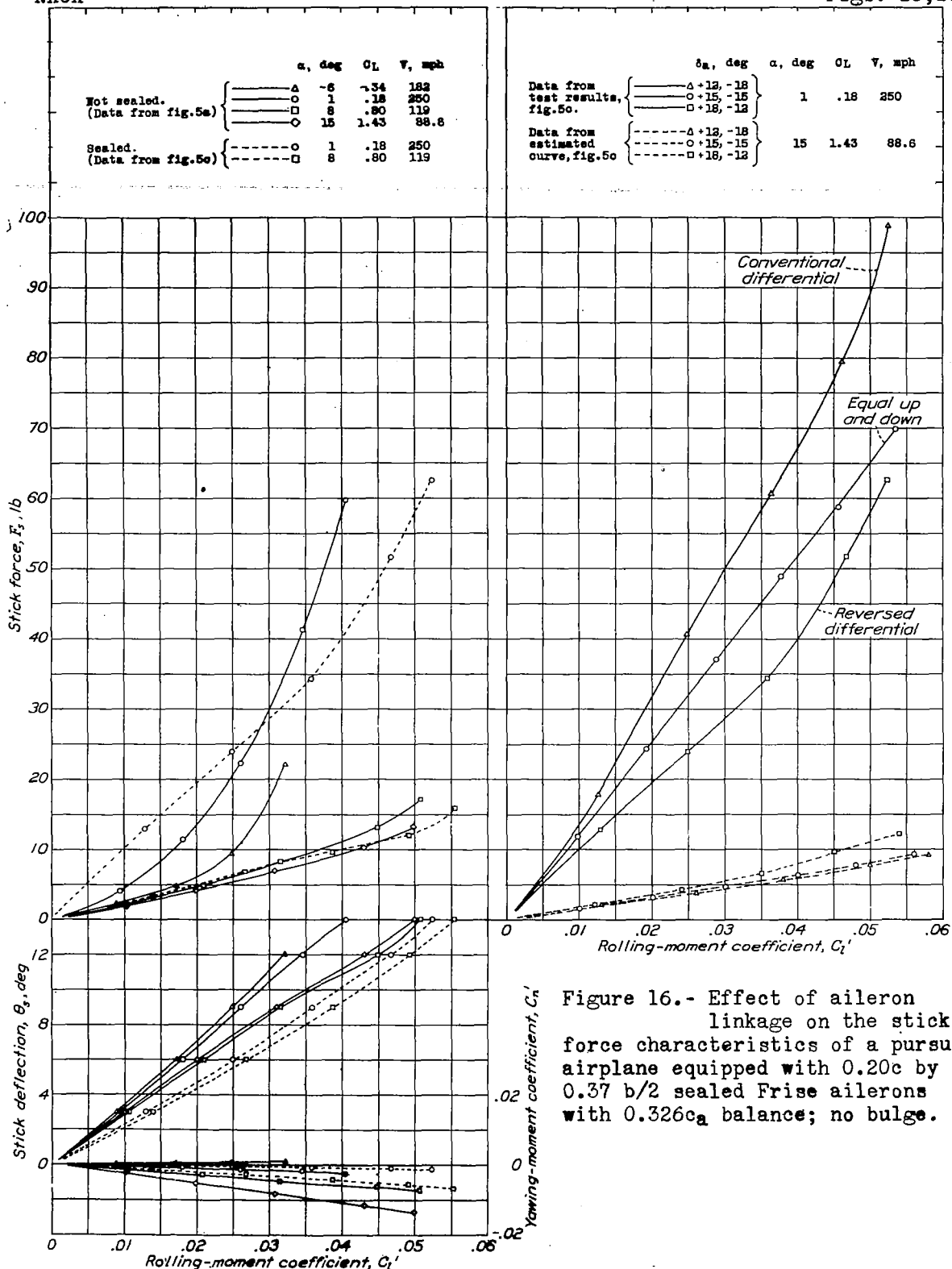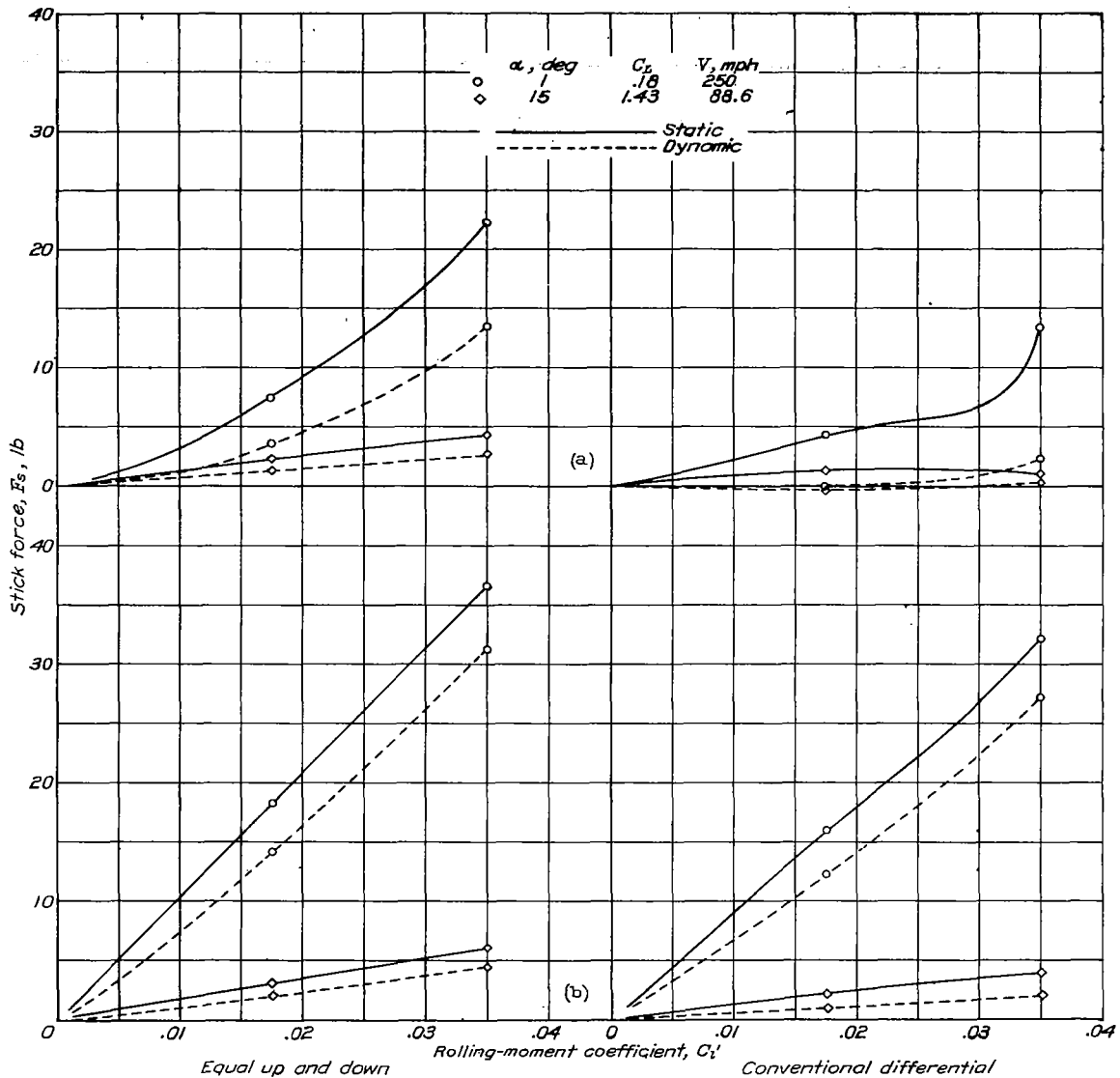
Figure 15.- Aileron-control characteristics of a pursuit airplane equipped with 0.20c by 0.37 b/2 Frise ailerons with 0.326c$_a$ balance. Reversed differential linkage. δ_a, 18°, -12°.

(a) Frise aileron with 0.326 c_a balance; no seal, no bulge.

(b) Plain sealed aileron with 0.326 c_a balance; top cover plate only.

Figure 17.- Effect of rolling on the stick-force characteristics of a pursuit airplane equipped with two arrangements of 0.20c by 0.37 b/2 ailerons and two aileron deflection systems.